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Estimation of Sedimentary Thickness of Part of Anambra Basin Nigeria using Aeromagnetic Data

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Abstract

This paper estimated the sedimentary thickness of part of Anambra Basin Nigeria using Aeromagnetic data. The study area is part of Anambra Basin, South Eastern Nigeria. Geographically, it is located between Longitude 7000'E – 7030'E and Latitude 6000'N – 6030'N. Three methods were used in the estimation –graphical method (which gave an overall average thickness of 2.4km), spectral analysis method (which yielded average thickness of 3.95km) and Euler deconvolution method (which verified the depths while giving insight on structures involved).These thickness values are in agreement with previous works thereby negating the possibility of appreciable petroleum accumulation in this area. Umuagu and Ugbene regions are minor exceptions though, due to their relatively thicker values (above average) and their favourable Euler solutions which qualify these regions for mineralization and hence mineral prospecting interests.

Key words: Allocyclic events, Anticlinal domes, Igneous intrusions, Half-Slope, Vitrinic reflectance.

Introduction

A sedimentary basin is any depression that has accumulated sediment from the basement rocks. If it contains numerous magnetic rock unit such as igneous intrusions or extrusive, magnetic sediments or magnetic metamorphic units, these can provide information on the morphology of the sedimentary basin and its structure. However, if the magnetic units in the basement occur at the basement surface, then the depth determinations for these will map the basin floor morphology. This approach has been used for several decades to locate sedimentary basins with significant thicknesses of sediment (Gunn, 1997).

Igneous rocks have higher content of magnetic minerals, especially magnetic than sedimentary rocks and can be identified and mapped in the sedimentary basin from the magnetic data. Igneous features such as intrusive plugs, dykes, sills, lava flows and volcanic centres can occur at any stage of a basin's evolution and therefore be preserved at any level in the sedimentary section. Such features are significant in understanding the history of a basin and assessing its petroleum or mineral prospectivity. Igneous intrusions can produce structural closure and here, magnetic anomalies can be indicators of hydrocarbon traps. Intrusions are not always recognized as such, seismic sections (and at various times) have been mistaken for simple anticlinal domes, salt and shale diaper and carbonate reef. The thermal effects of igneous intrusion can cause maturation of hydrocarbon source material without associated changes in vitrinic reflectance (Reeckman and Mebberson, 1984). Many works have been carried out in various parts of Nigeria on analysis of aeromagnetic data; these include that of Onwuemesi (1997) who applied 1D spectral analysis to aeromagnetic anomalies in the Anambra basin, Anakwuba *et al* (2011) used spectral methods to interpret aeromagnetic anomalies over Maiduguri-Dikwa depression of Chad basin. Nwosu (2018) also applied spectral analysis to evaluate aeromagnetic anomalies over parts of Upper Benue Trough Nigeria.

This study utilized Spectral Analysis method, Half- Slope method, and the Standard Euler Deconvolution method in estimating the average thickness of the sedimentary layers in the Anambra basin - with Udi as reference.

Geology of Study Area

The study area is part of Anambra Basin, south Eastern Nigeria, which lies between Longitude 7°00'E – 7°30'E and Latitude 6°00'N – 6°30N (fig. 1). The basin is 300km NE-SW trending syncline, located at the south western dip of the Benue trough in south eastern Nigeria. The trough is characteristically linear in shape and its sedimentary formations are continuous with the Nigerian Coastal Basin. It is characterized by Hills and Valleys.

This hills and ridges were formed due to the resistance of sandstones to agent of denudation (like erosions etc). The plains and the valleys were formed as a result of the shales that were not resistant to agents of denudation. Therefore, the landform is as a result of the difference in the degree of resistance to agents of denudation and the bedrock varies from basement complex to shales, marls, and limestone, as well as sandstones and unconsolidated to semi-consolidated sands.

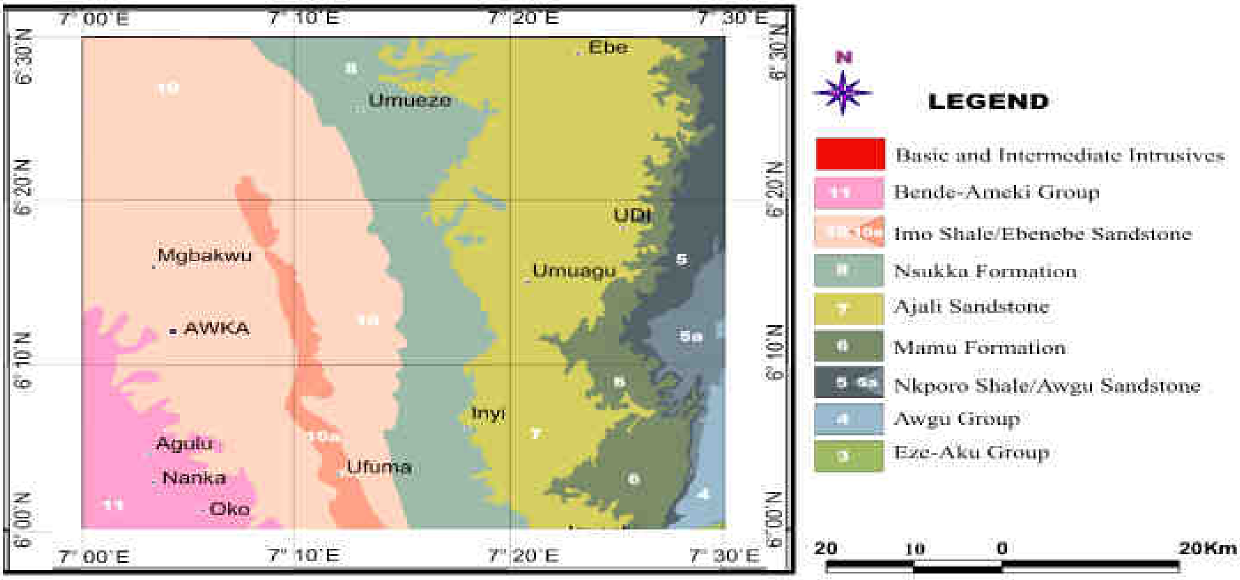

Fig.1. Geological map of study Area

Ukaegbu, (2009) established the geology of north-east of Afikpo basin consisting of two major litho-stratigraphic units of sandstone ridges and low-laying shale each of which forms a significant component of the Middle Albian Asu River Group and Turonian Ezeaku formation. He aimed at examining the lithology and their stratigraphic relationships with a view to drawing inferences on the geology, provenance, depositional history and environment of the deposition of the sedimentary bodies in the area. Furthermore, the repeated allocyclic incursions of the sea resulted in characteristic basin-wide genetic sequences (Bush, 1971; Galloway, 1989), or parasequence sets (Van Wagoner et al., 1988). Two allocyclic events have been recognized in the Anambra Basin that encompass large time intervals.

The numerous shallow intrusions in the Upper Benue basin occur substantially outside the basement surface in the region and show a gentle general southward increase with mean depth value ranging from 2km in the northern area to 2.62km in the south (Nwodgo et al. 1991); this is associated with the deposition of Awgu shale around Agbani. Turonian transgression, which marked the start of this cycle, is believed to have commenced from the Gulf of Guinea through the Anambra basin to the Benue Trough. Most of the deposits of this cycle have been eroded as a result of the upper Cretaceous tectonic activity. The fourth sedimentary cycle was marked by deposition of the Nkporo Shales, Owelli Sandstones, Afikpo Sandstones and Enugu shales during the Campanian-Maastrichtian transgressive phase. This cycle also marked the deposition of the coal measures including: the Mamu Formation, Ajali Sandstones and Nsukka Formation. This frame work has been the basis for most subsequent stratigraphical analysis (Zaborski et al, 1998). Similarly, Kangoko et al. (1997) using spectral analysis of residual magnetic field over the middle Cross River Basin, determined the basement depths in the area. They discovered that the depth to the first layer varies from 0.258km to 1.424km with an average value of 0.698km while the second magnetic layer varies from 2.030km to 5.057km with an average value of 3.121km; he deduced that throughout the basin, depths to the basement surface vary from about 1km to about 4km.

Theory and Method

The aeromagnetic maps used for the study were obtained from the Geological Survey of Nigeria. The nominal flying altitude above the terrain was 500 feet (approximately 152m) with flight line and tile line spacing of 2km and 20km respectively. However, the flight and tie line direction is $150^o/330^o$ and $60^o/240^o$ respectively. The regional correction of the magnetic data was based on IGRI (Epoch data, 1 January, 1974). The first phase of digital processing of the contoured aeromagnetic total intensity field map on 1:100,000 (Plate 1) was digitization. The map was digitized manually with a 2cm by 2cm (equivalent to 2km by 2km) grid spacing. The method of interpolation adopted is the Kriging method. This method determines the most probable value at each grid-node from the surrounding real data values. This was done by noting the coordinates (X and Y) and magnetic value (Z), forming a XYZ file. This is continuously done at every grid-node interval across the flight-lines.

Several potential field software with different analytical modules were used these include; Geosoft Oasis Montaj 8.3. HJ version, Surfer 10, and Matlab 8.1. Regional – residual separation was carried out using polynomial fitting – an analytical technique in which matching of the regionals by a polynomial surface of low order exposes the residual features as random errors. The Polynomial residue map was then subject to the Fast Fourier Transformation software (FFTIL) to perform further analysis.

Reduction to the Pole (RTP) which removes the effects of geomagnetic latitude by applying a mathematical filter to the gridded data to produce an anomaly map that would have resulted had the area of interest been surveyed at the magnetic pole (Reynolds, 2011) was performed. Similarly, the first and second Vertical Derivatives which are equivalent to observing the vertical gradients directly with a magnetic gradiometer and have the same advantages namely - enhancing shallow sources, suppressing deeper ones, and giving a better resolution of closely-spaced sources (Reeves, 2005) were also performed. Upward and Downward Continuation filters which transform the data to what it would have been if the measurements had been made at different heights above the source (Dentith and Mudge, 2014) were as well carried out.

Power spectrum computes the thickness of the sedimentary basin and that of the crustal Moho depth. The spectral depth method is based on the principle that a magnetic field measured at the surface can therefore be considered the integral of magnetic signatures from all depths. The power spectrum of the surface field can be used to identify average depths of source ensembles (Spector and Grant, 1970). This same technique can be used to attempt identification of the characteristic depth of the magnetic basement, on a moving data window basis, merely by selecting the steepest and therefore deepest straight-line segment of the power spectrum, assuming that this part of the spectrum is sourced consistently by basement surface magnetic contrasts. These depths were established from the slope of the log- power spectrum at the lower end of the total wave number or spatial frequency band. The method (therefore) allows an estimate of the depth of an ensemble of magnetized blocks of varying depth, width, thickness and magnetization.

Peters' Half-Slope method (Fig. 2) was also used to estimate depths in this study. Here, a tangent (Line 1) is drawn to the point of maximum slope and, using a right-angled triangle construction, Line 2 with half the slope of the original tangent is constructed. Two further lines with the same slope as Line 2 are then drawn where they form tangents to the anomaly (lines 3 and 4). The horizontal distance, *d*, between these two tangents is a measure of the depth to the magnetic body "z", estimable via equation (1) (Peters, 1949).

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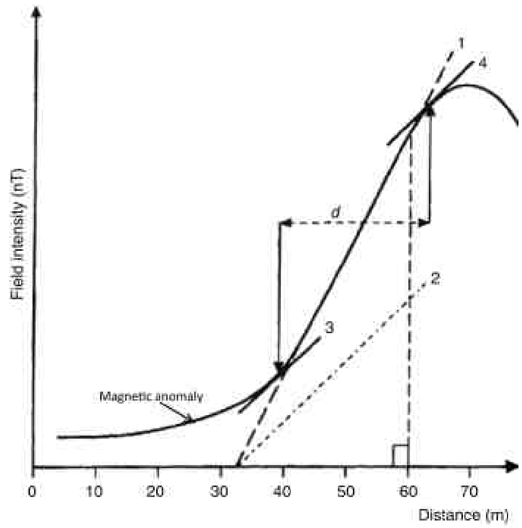


Fig. 2. Sketch for Peters's half –slope method

$$z = (d \cos \alpha)/n \tag{1}$$

where *d* is the horizontal distance between half-slope tangents; $1.2 \leq n \leq 2$, but usually $n = 1.6$; α is the angle subtended by the normal to the strike of the magnetic anomaly and true north.

The Standard 3D Euler method is based on Euler's homogeneity equation (equation 2), which relates the potential Field (magnetic or gravity) and its gradient components to the location of the sources, by the degree of homogeneity N, which can be interpreted as a structural index The method makes use of a structural index in addition to producing depth estimates. In combination, the structural index and the depth estimates have the potential to identify and calculate depth estimates for a variety of geologic structures such as faults, magnetic contacts, dykes, sills, etc. The algorithm uses a least squares method to solve Euler's equation simultaneously for each grid position within a sub-grid (window).

$$(x - x_o)\frac{\delta T}{\delta x} + (y - y_o)\frac{\delta T}{\delta y} + (z - z_o)\frac{\delta T}{\delta z} = N(B - T) \tag{2}$$

With "B" the regional value of the total magnetic field and (x_o; y_o; z_o) the position of the magnetic source, which produces the total field T measured at (x; y; z). Table 1 summarizes the structural indices (SI) for given geologic models. The number of infinite dimensions describes the extension of the geologic model in space.

Table 1: Structural Indices for Simple Magnetic Models Used For Depth Estimations by 3D Euler Deconvolution.

Geologic Model	**Number of Infinite Dimensions**	**Magnetic Structural Index**
Sphere	0	3
Pipe	1 (z)	2
Horizontal cylinder	1 (x-y)	2
dyke	2 (z and x-y)	1
sill	2 (x and y)	1
contact	3 (x,y,z)	0

Results and Interpretation

The total aeromagnetic intensity map of study area is shown in fig. 3, from which one could observe high magnetic anomalies in the range of 7910 to 7970 gammas. The high areas are in red to pink colours while the low areas are in light- green to deep-blue colours. The low relief areas encompass; Ugbene and Umuagu hence these areas may occupy pronounced sedimentary thickness. The 3D aeromagnetic surface (wireframe) map is shown in fig.4 from which one could conspicuously notice the low and high magnetic relief areas.

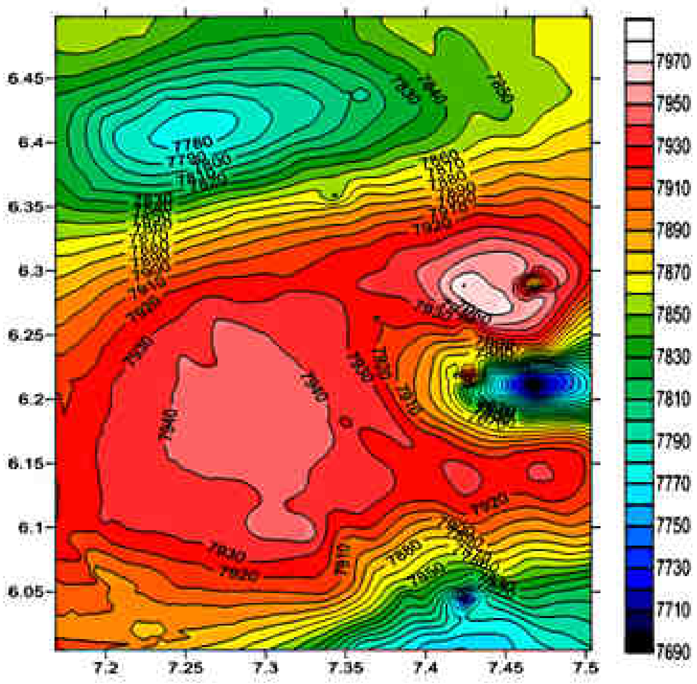


Fig. 3 Total Magnetic Intensity field map of study area

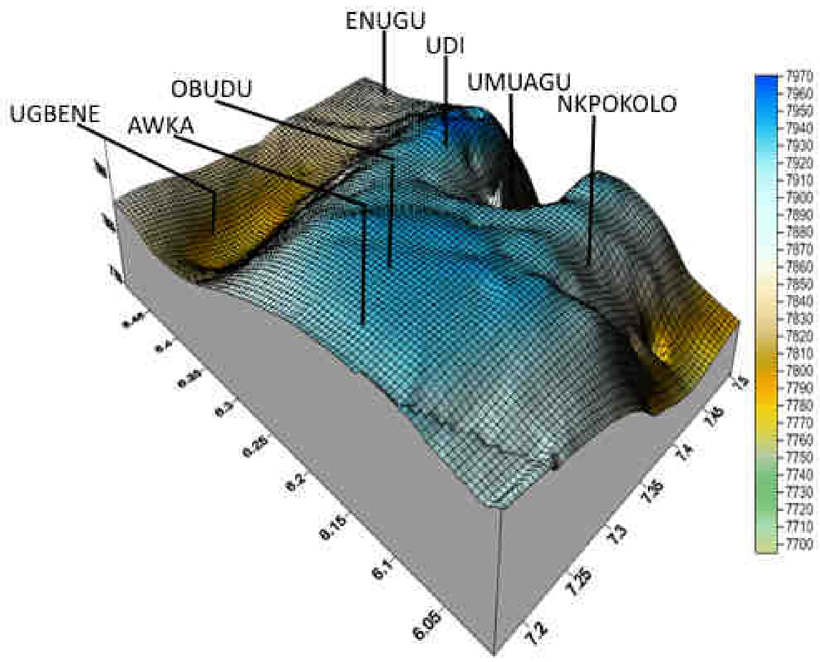


Fig. 4 3D Total (surface) Magnetic field map of study area

The areas with high magnetic intensity are indicated as uplifted areas with the highest points being the blue shaded areas, this blue coloured areas have the highest basement relief of the study area (e.gs are Awka, Obudu and Udi).

The second Degree residual map is shown in fig. 5 from which one could relatively confirm that the far Northern region is magnetically low while the central portion is very high.

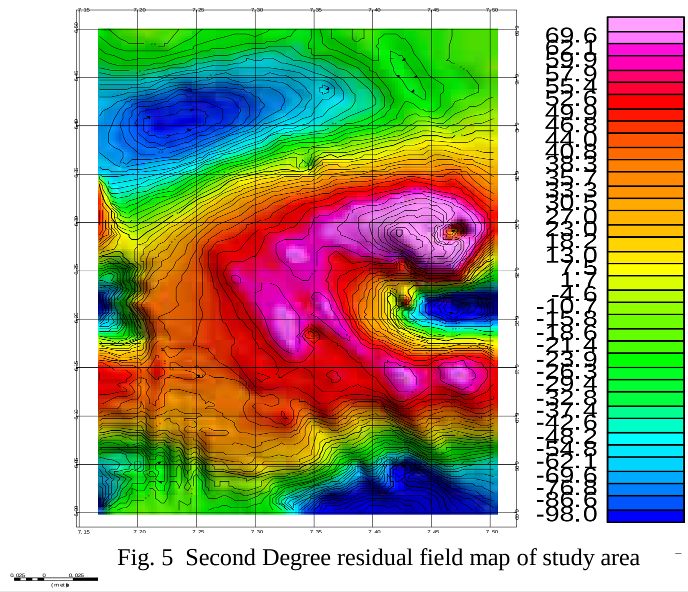


Fig. 5 Second Degree residual field map of study area

Graphical methods of depth estimation were performed on some linear magnetic anomalies within the data after choosing six profiles (with UDI as reference). The profiles are as named; Profile [A] = 9km South of Amadim; Profile [B] = Udi town; Profile [C] = 12km South East of Udi; Profile [D] = 7.5km west of Enugu; Profile [E] = 4km North West of Inyi and Profile [F] = 10km North West of Agwu. There plots are displayed in fig. 6 while the depth estimations resulting from them (using Peter's slope method, Tiburg, and Hannel methods) are tabulated in table 2 from which we estimated average Sedimentary thickness as 1.55km, 3.22km, and 2.39km for the three aforementioned methods respectively.

Table 2: Estimation of depth to magnetic sources (graphical methods)

TOWN	COORDINATE		DEPTH ESTIMATION IN KM			WIDTH (KM)	AMPLITUDE (GAMMA)	MAGNETIZATION (A/M)	I% RADIAN	TYPE OF ANOMALY
UDI	LAT	LONG	PETER'S SLOPE	TIBURG	HANNEL					
A	6.4106	7.2545	3.285	4.941	3.648	8.5	7775	0.61	1.23	LOW
B	6.2075	7.1967	2.285	5.342	3.948	7.0	7960	1.04	1.31	HIGH
C	6.2129	7.4693	0.7855	1.858	1.348	8.0	7780	0.52	1.19	LOW
D	6.4578	7.4241	1.348	3.667	2.698	7.0	7849	1.21	1.17	LOW
E	6.1371	7.3023	0.410	1.180	0.848	5.5	7950	2.44	1.32	HIGH
F	6.1453	7.4187	1.1605	2.348	1.848	7.0	7931	2.11	1.35	HIGH

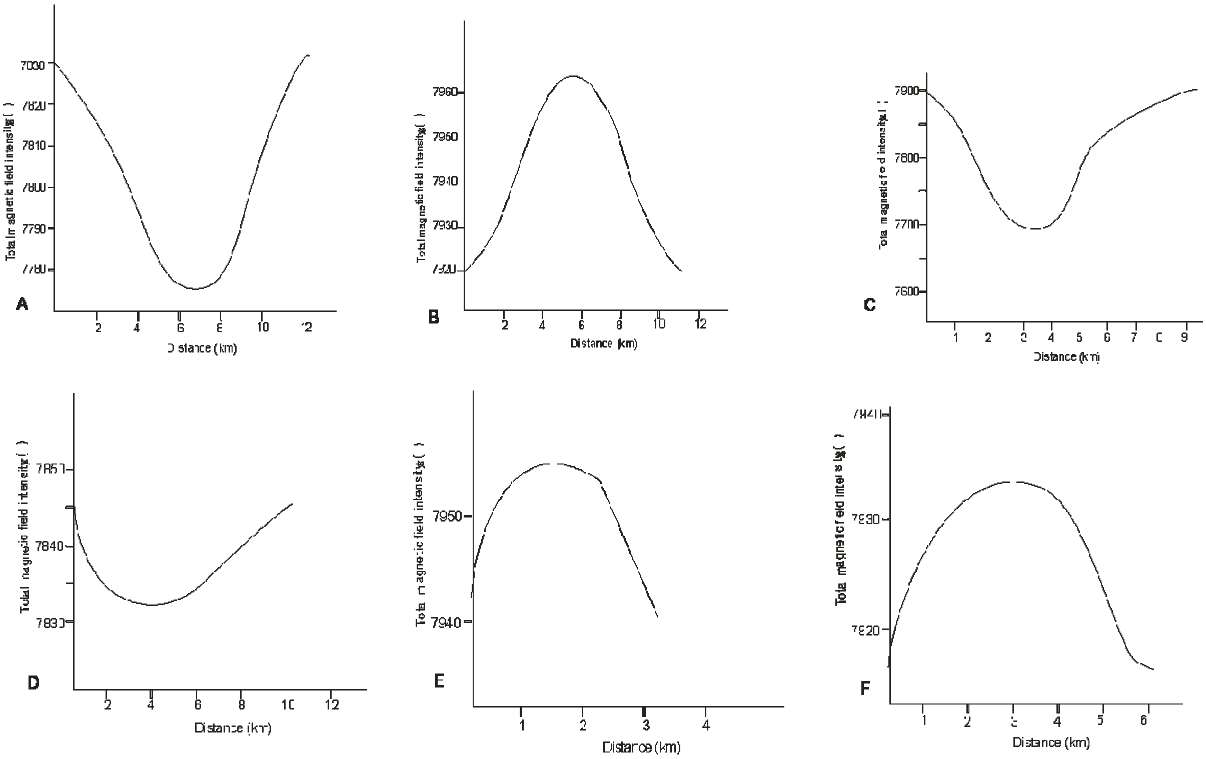


Fig. 6 Anomalies from Profiles A- F

Spectral analysis approach that involved splitting our study area into four blocks – still UDI as reference, yielded the plots expressed in fig. 7 from which estimates of two depths (D_1 - for shallower and D_2 - for deeper sources) were made as highlighted in table. 3. D_1 ranged from 0.79km to 3.29km while D_2 (the main sedimentary thickness of interest) ranged from 1.89km to 5.34km with an average value of 3.95km. A closer examination of Profile [B] in table 2 together with the 3D surface map of the study area suggest that the thickest section of this study area is around the southern part of Udi town.

Adopting Euler deconvolution method to further verify depths and to throw light on the possible structural interpretations of the magnetic sources gave rise to the figures shown in figure 8 (a – d). A closer look at fig. 8a (for contact) reveals the contact irregularity resulting from the sedimentary bottom and igneous basement; deeper values are deducible for southern part of Udi around Umuagu and south eastern part of Inyi. Fig. 8b reveals the possibility of deep rooted sills around Ugbene which is a pointer to possible mineralization.

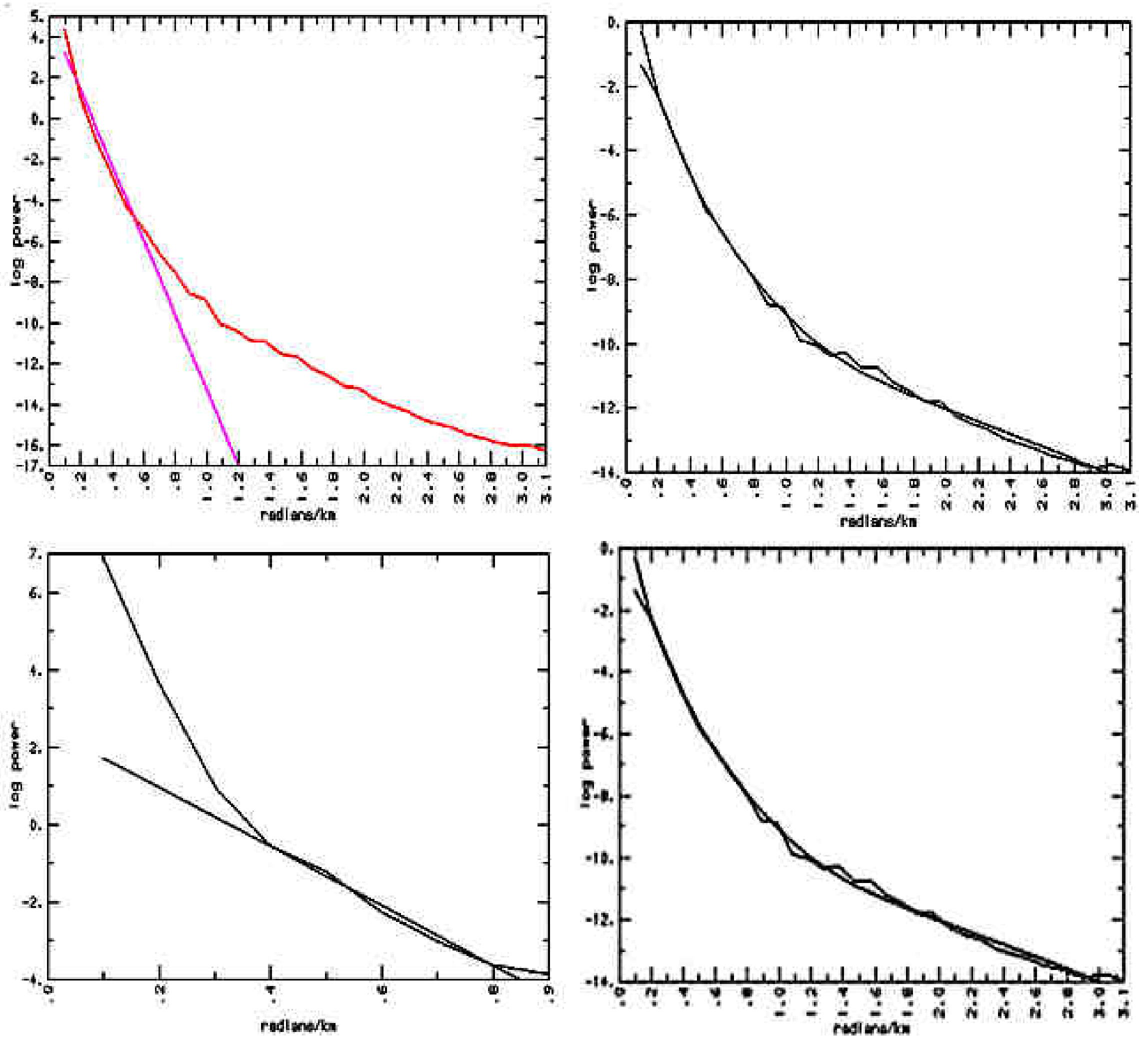
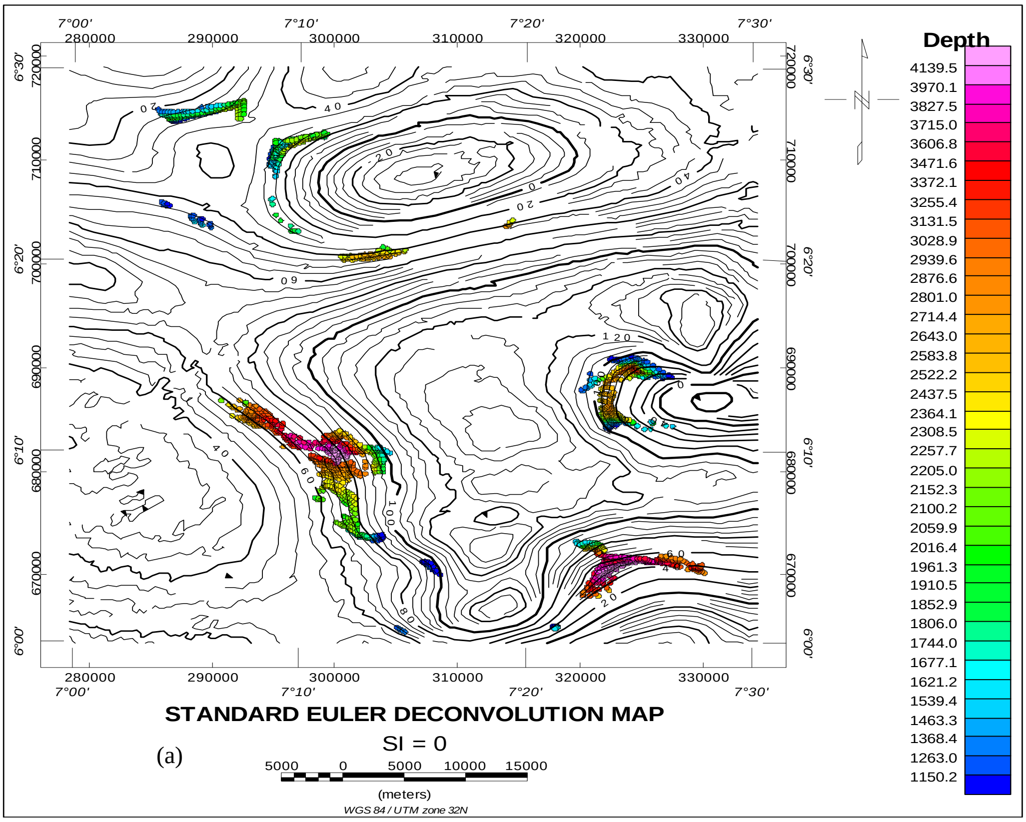


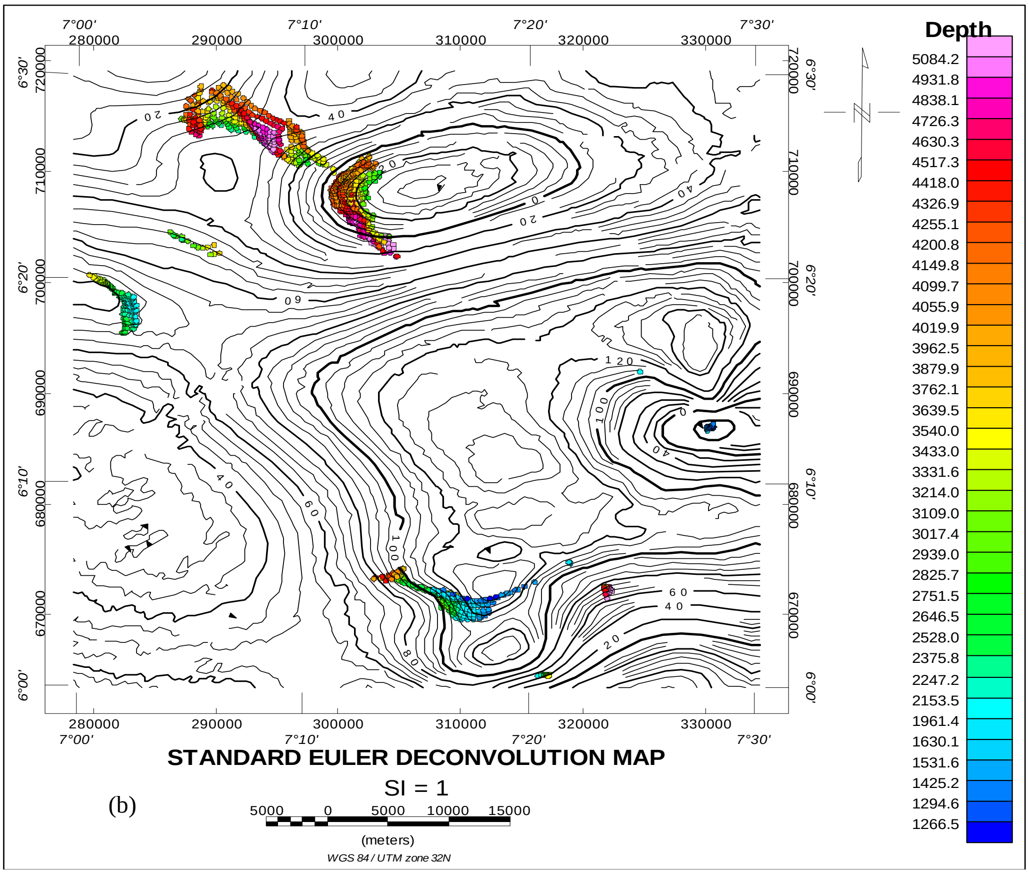
Fig. 7 Spectral plots of the study area

Table 3: Estimation of depth to magnetic sources (Spectral method)

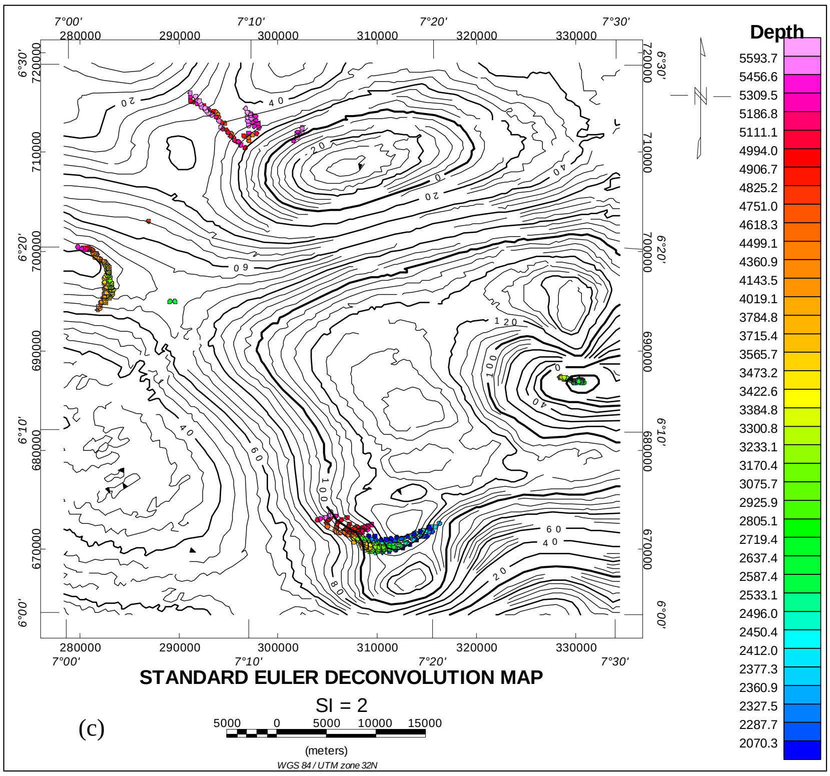
TOWN	X1	X2	Y1	Y2	ESTIMATED DEPTHS(KM)	
					D1	D2
Udi	7.00	7.25	6.00	6.25	3.285	4.941
	7.00	7.25	6.25	6.50	2.285	5.342
	7.25	7.50	6.00	6.25	0.785	1.858
	7.25	7.50	6.25	6.50	1.348	3.667


Depth
4139.5
3970.1
3827.5
3715.0
3606.8
3471.6
3372.1
3255.4
3131.5
3028.9
2939.6
2876.6
2801.0
2714.4
2643.0
2583.8
2522.2
2437.5
2364.1
2308.5
2257.7
2205.0
2152.3
2100.2
2059.9
2016.4
1961.3
1910.5
1852.9
1806.0
1744.0
1677.1
1621.2
1539.4
1463.3
1368.4
1263.0
1150.2
STANDARD EULER DECONVOLUTION MAP
SI = 0
(meters)
WGS 84 / UTM zone 32N

(a)


Depth
5084.2
4931.8
4838.1
4726.3
4630.3
4517.3
4418.0
4326.9
4255.1
4200.8
4149.8
4099.7
4055.9
4019.9
3962.5
3879.9
3762.1
3639.5
3540.0
3433.0
3331.6
3214.0
3109.0
3017.4
2939.0
2825.7
2751.5
2646.5
2528.0
2375.8
2247.2
2153.5
1961.4
1630.1
1531.6
1425.2
1294.6
1266.5
STANDARD EULER DECONVOLUTION MAP
SI = 1
(meters)
WGS 84 / UTM zone 32N

(b)



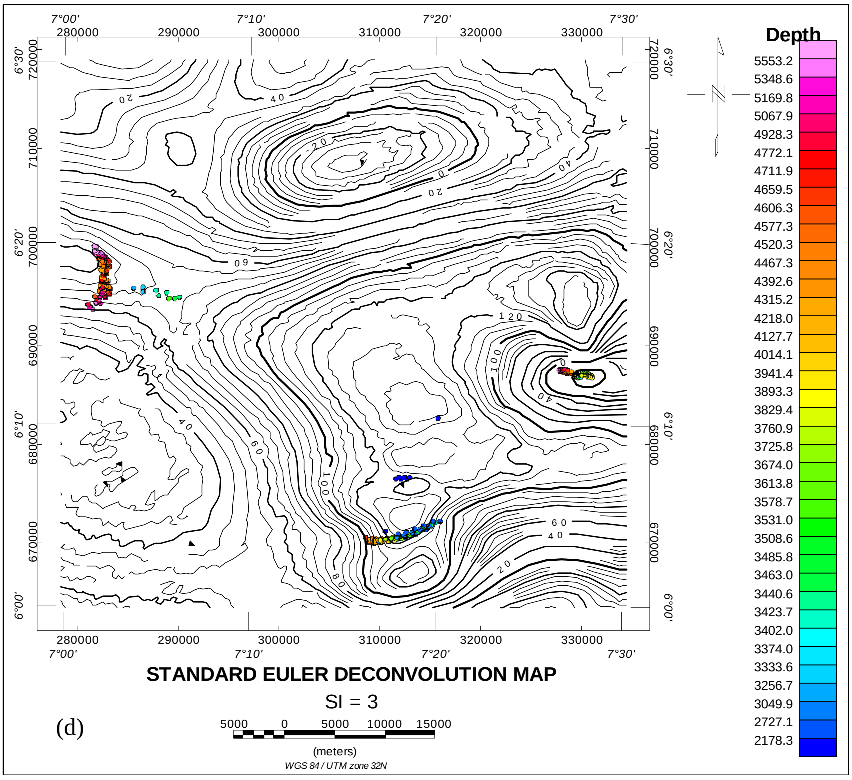


Fig. 8 (a-d) : Standard Euler solution maps of the study area.

Conclusion

The study transcended through three major methods of estimating depth to magnetic sources in geophysics namely; graphical methods, spectral analysis method, and Euler deconvolution method. Here they were adopted to estimate the sedimentary thickness of part of Anambra basin. The Analyses gave results in tandem with previously published works in the value of 3.95km as the average sedimentary thickness of part of this basin under study (as revealed by the spectral method) although graphical methods yielded overall average thickness of 2.4km. These values are rather too low to support quantifiable hydrocarbon maturation and accumulation.

A leeway for possible solid mineral accumulation is provided by the Euler solution (fig. 8b) where deep- seated sills and dykes are predicted around Ugbene and South eastern Inyi regions.

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